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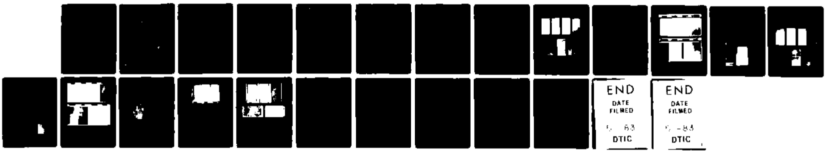

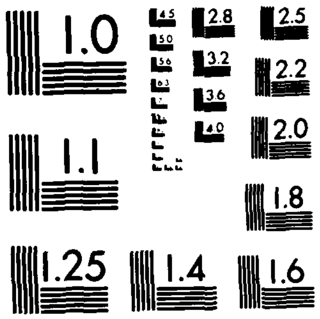

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CORROSION EVALUATION OF STOVE PIPE MATERIALS AND SURFACE TREATMENTS

JOSEPH J. FALCO and MILTON LEVY

METALS RESEARCH DIVISION

February 1983

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Prepared for
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ABSTRACT

Due to the severe corrosion encountered by fielded blue-oxide finished mild steel stove pipes, the corrosion behavior of alternate stove pipe materials/coatings was assessed. Assessment was based on results of corrosion tests which simulated the operational environment. The data indicated that 310 stainless steel, aluminized, galvanized, and chromium plated mild steels can extend stove pipe service life significantly. Aluminized mild steel appears to be the most cost-effective substitute for the presently used material.

CONTENTS

INTRODUCTION

Steel stove pipes, given a bluing surface treatment, are currently utilized by the U.S. Army to exhaust harmful flue gases formed during the operation of tent heaters or stoves. Reportedly, these stove pipes have been severely corroded after a short time in service. During field use, stove pipes are subjected to heating/cooling cycles which result in moisture condensation on the cooled steel surface. Consequently, severe rusting of stove pipes ensues. The replacement cost of stove pipes resulting from corrosion is reported to be $170,000 per year.

A blue finished mild steel affords minimal corrosion protection under conditions to which stove pipes are normally exposed. To mitigate the corrosion that occurs, an alternate material or preferably a more effective surface treatment or coating is required.

Normally, steel sheet is protected from corrosion degradation by surface treatments or coatings that in effect insulate the steel surface from harmful environments, i.e., moisture, salt, and elevated temperatures. The application of such protective coatings involves treatment directly to the final fabricated product or treatment to steel sheet in a continuous operation. Protective coatings or treatments applied to finished products usually are more costly and result in non-uniform thicknesses because of the geometry of the part, but protective treatments applied directly to steel sheet coils that can be successfully fabricated to a desired shape ensure uniform coverage over the entire surface at the lowest possible cost.

The ultimate goal of this investigation is to select corrosion-resistant material systems (steel/coatings, steel/surface treatments, or alternate material) that have the potential to enhance stove pipe service life and to be cost effective.

MATERIALS AND EXPERIMENTAL PROCEDURES

Materials

Materials selected for testing were in the form of commercially available stove pipes fabricated from mild steel (1020) with the following coated finishes:

(a) blue oxide
(b) black matte oxide
(c) black enamel paint
(d) chrome plate
(e) galvanized steel

Also, aluminized steel containing 5% to 10% silicon and type 310 stainless steel, obtained in the form of sheet stock, were evaluated as alternate candidate stove pipe materials.

Table 1 lists the materials evaluated with a brief description of the coating application technique and thicknesses produced on commercially available material systems (thicknesses obtained from vendors).

Table 1. CANDIDATE STOVE PIPE TEST MATERIALS

Material	Material Form	Thickness-Inches (Nominal)	Coating Thickness Inches/Side (Nominal)	Remarks on Coating Application
Blue Finish Steel	6-Inch Stove Pipe	0.015	Blue Tint	Oxide Coat Heated steel passed through steam
Matte Finish Steel	6-Inch Stove Pipe	0.024	0.00015	Oxide Coat (a) Heated steel passed through steam (b) Varnish applied and furnace cured
Black Enamel Steel	6-Inch Stove Pipe	0.024	0.00015	Paint Coat Dipped in black enamel paint
Chrome Coated Steel	6-Inch Stove Pipe	0.014	0.0000704	Electrolytic Coat Cu / Ni / Cr Outside Surface: 0.00005" 0.00002" 0.0000004" Inside Surface: 0.00005" 0.00002"
Galvanized Steel	6-Inch Stove Pipe	0.024	0.00055	Galvanized Coat Hot Dipping
Aluminized Steel	Sheet	0.035	0.0008	Aluminum Coat Type I aluminum coat containing 5.0-10.0% Si - Hot Dipping
Type 310 Stainless Steel	Sheet	0.025	--	No Coating Alloy Composition: 24.0-26.0Cr, 19.0-22.0Ni, 0.25C, 2.0Mn, 1.5Si, 0.045P, 0.030S

Experimental

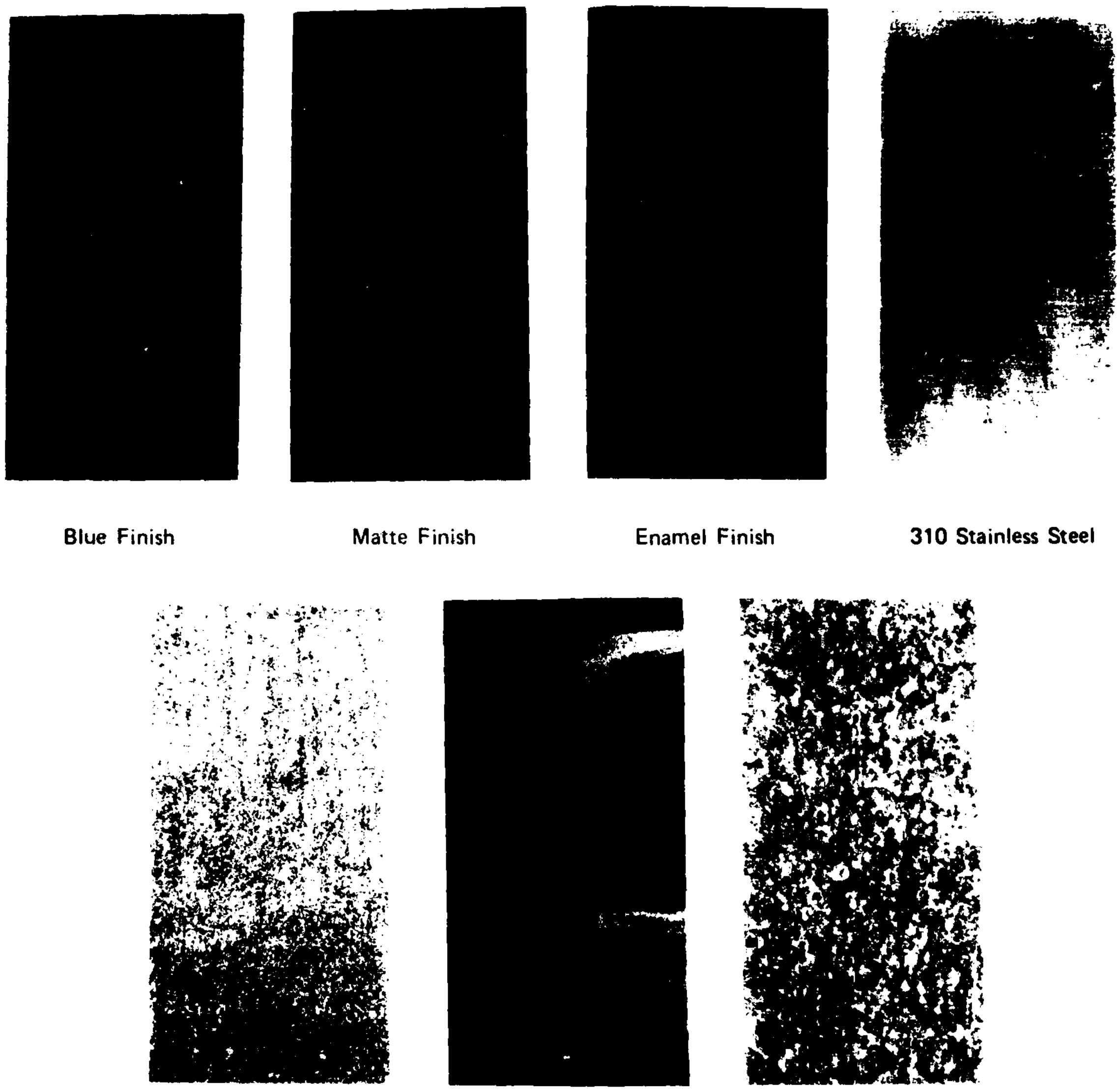
Environmental exposure tests were performed on a laboratory scale to assess the corrosion resistance of candidate materials. Tests to simulate the more common environments that stove pipes are exposed to include 900°F to RT (room temperature) cyclic oxidation, 95% relative humidity, and 5% salt spray exposures. Except for the black enamel coated specimens, all specimens were rinsed in acetone and dried prior to testing. All tests were run with triplicate specimens. A brief description of the testing program follows:

(a) Cyclic Oxidation - Rectangular specimens, 2" by 4", were positioned vertically in a slotted alumina holder which in turn was placed in a muffle furnace operating at 900°F. Specimens were oxidized at temperature in quiescent air for 8 hours per day, removed from the furnace, and air cooled at room temperature (16 hours). This cycle was repeated for 40 days.

(b) 95% Relative Humidity at 120°F - Specimens fabricated in a rectangular form, 2.5" by 4.5", were positioned vertically on a slotted Plexiglas holder which in turn was inserted into a controlled humidity chamber.

(c) Salt Spray - Rectangular specimens 6.5" by 3.5" were utilized in the fog-type spray test described in ASTM B117-73. The cut edges of coated specimens were protected with a wax to prevent any galvanic effect between the substrate and the coating surface.

Specimens from all tests were visually observed on a daily basis for corrosion effects, and in tests a and b, they were weighed periodically. The typical appearance of test panels of the candidate materials prior to test (900°F cyclic oxidation) is shown in Figure 1. The unusual pattern observed on the chrome-plated specimen is due to the light reflecting from its highly glossy surface.



Blue Finish — Matte Finish — Enamel Finish — 310 Stainless Steel

Aluminized Steel — Chrome Plate — Galvanized

Oxidation Test Specimens

Figure 1. Test panels prior to test.

RESULTS AND DISCUSSION

Cyclic Oxidation

For oxidizing panel specimens with various surface treatments, 900°F was selected as the optimum temperature because it more closely approximates the maximum temperature encountered by stove pipes during service. Also, to simulate service use on a daily basis, a thermal cyclic exposure consisting of 8 hours at temperature followed by 16 hours at room temperature was employed. Figure 2 shows oxidation weight-change curves representing exposure to cyclic static oxidation conditions over a 40-day time period (run in triplicate). Figure 3 shows specimen visual appearance after tests. At the onset of oxidation, small amounts of vapor were emitted from all material systems, except for the enamel material from which a copious amount of vapor escaped. Customary mill practice is to protect bare and coated coil sheet with a protective oil film. Evidently, this oil was not completely removed during the specimen cleaning operation. Therefore, weight change which occurred during the first 8 hours of exposure represent the net effects of oxidation products formed (weight gain) and oil film volatilization (weight loss). Vapor from the black enamel coatings was primarily due to the volatilization of the organic vehicles employed as carriers in the paint.

The black matte and blue finished mild steel materials, both with an oxide surface coating, are the most susceptible to cyclic oxidation based on their accelerated oxidation rates, as shown in Figure 2. The reaction products formed, as shown in Figure 3, are characterized by a dark brown, powdery, uniform layer which is pervious to oxygen ingress to the substrate. Apparently, these oxide finishes do not prevent substrate oxidation and appear to be poor choices for providing oxidation resistance at moderate temperatures (to 900°F).

A copper flash plus nickel plated mild steel, only one side of which received a subsequent chromium plate, exhibits a minimal increase in weight during the first 15 hours, due to initial protective oxide (Ni and Cr) formation. However, after 15 hours of exposure, an increase in oxidation rate is observed because of localized corrosion on the nickel plated side, as shown in Figure 3. Localized Ni plate failure occurred as pits, suggesting a degree of porosity was inherent in the electroplated Ni applied to a minimal thickness of 0.00002". Prior to localized failure,

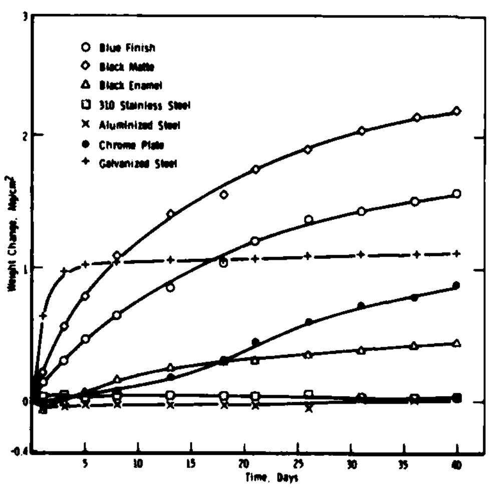
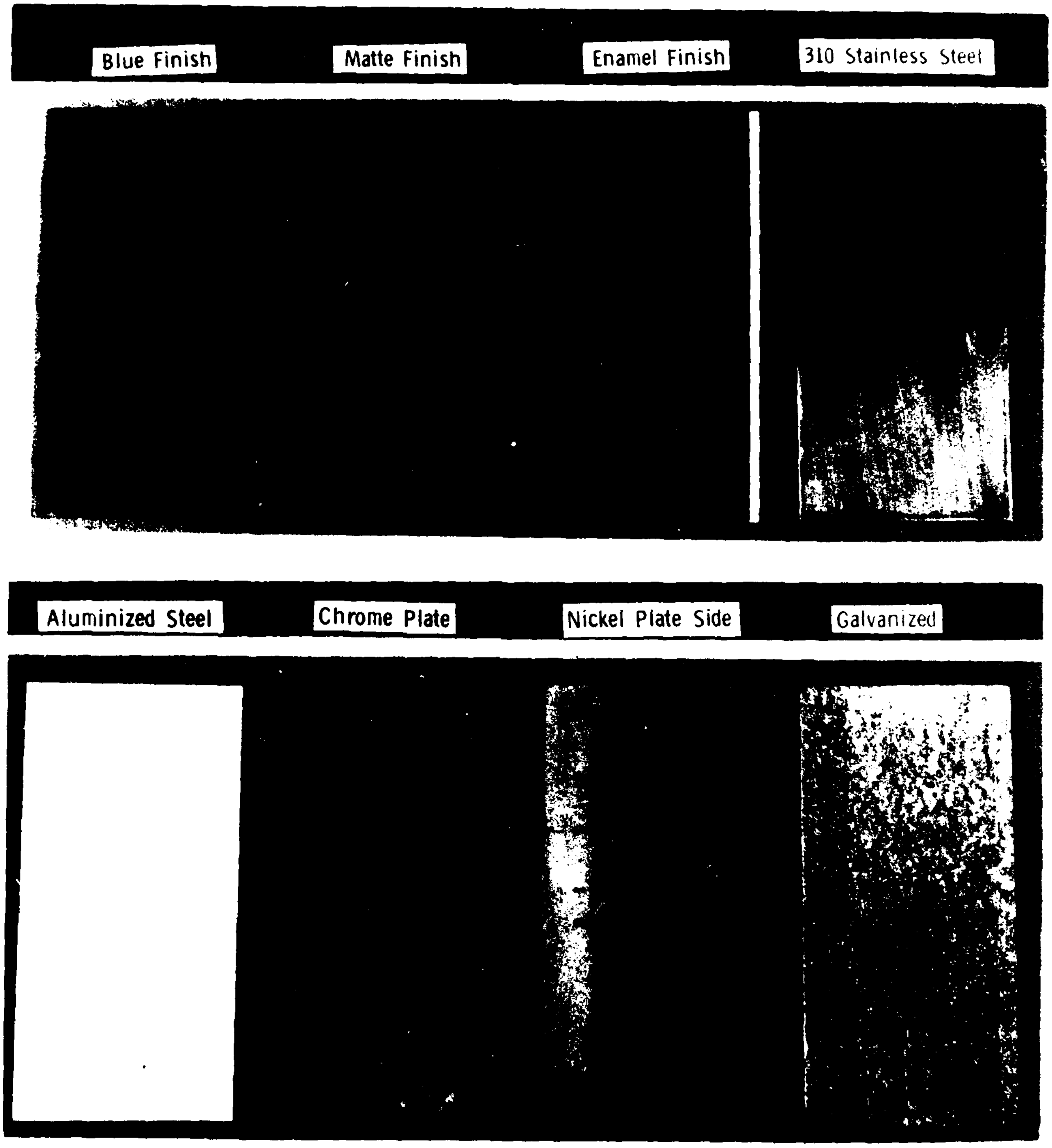


Figure 2. Reaction rates of candidate stove pipe material systems exposed to 900°F cyclic oxidation.



900°F thermal cyclic test specimens (after 40 days of testing)

Figure 3. Test panels after test.

the nickel side exhibits a uniformly thin, dark gray adherent oxide rather than the normal nickel metallic luster shown in Figure 4. The thin uniform and adherent oxide layer formed on the chromium side has a bright blue oxidized appearance.

A marked oxidation rate decrease occurs when mild steel is coated with a heat resistant enamel paint when compared to the performance of oxide finishes (matte or bluing) produced by specific heat treatments (Figure 2). The uniform reaction product layer (dark brown) is similar in appearance to that obtained with either a matte or blue finish, as shown in Figure 3. However, the oxide layer produced has a denser texture than those resulting from oxide type finishes. The lower reaction rate and denser scale indicate that the enamel finish affords more protection against oxidation than either oxide finish.

The remaining rate curves shown in Figure 2, for galvanized steel, aluminized steel, and type 310 stainless steel, exhibit negligible weight change after an initial weight gain. Initially, a weight gain occurs due to protective oxide formation (thin dense films) that provides all three systems excellent oxidation with protection for times up to 40 days under the conditions employed. There is no detectable color change of the aluminized steel panel after exposure, but the galvanized steel and stainless steel panels become gray and blue-black respectively (see Figure 3).

Based on the oxidation curves of Figure 2, the material systems can be ranked in order of decreasing oxidation resistance as follows: 310 stainless steel > aluminized > galvanized > enamel paint > chrome plate > bluing > matte. There is a shift in the chrome plate ranking after approximately 15 hours of exposure. This anomaly occurs due to local corrosion on the nickel plate side and could be rectified by increasing the plate thickness to alleviate local corrosion. Without local

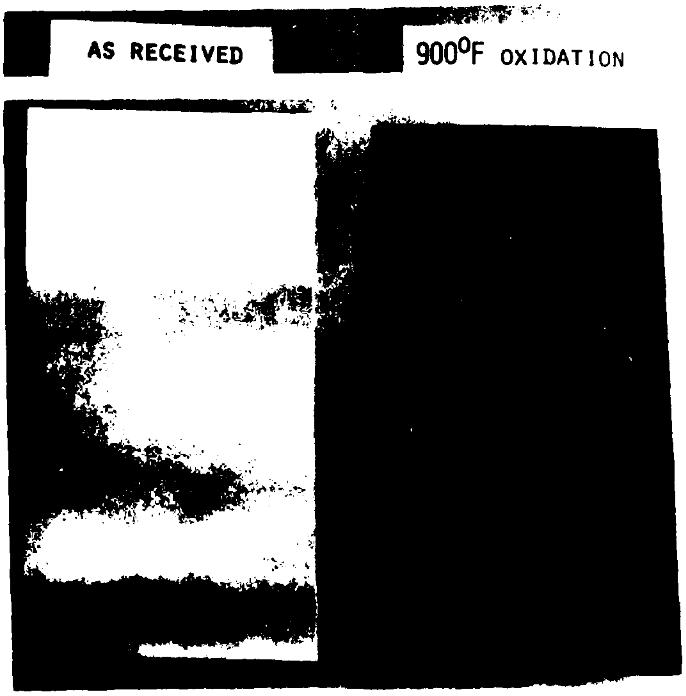


Figure 4. Nickel plated mild steel.

corrosion, the chrome plate oxidation rate would remain below that of a matte finish and hence this material would achieve a ranking at least comparable to the galvanized material.

Humidity

Figure 5 displays humidity test specimens after 14 days of test (95% R.H. at 120°F) at which time the first visible signs of corrosion were observed. Both oxide surface treatments, blue and matte finishes, reveal that pitting is the mode of corrosion attack. Aluminized and galvanized specimens exhibit a non-uniform surface attack with dark gray and white reaction products, respectively, due to oxide formation. The white oxide consists mainly of ZnO_2 while the dark gray

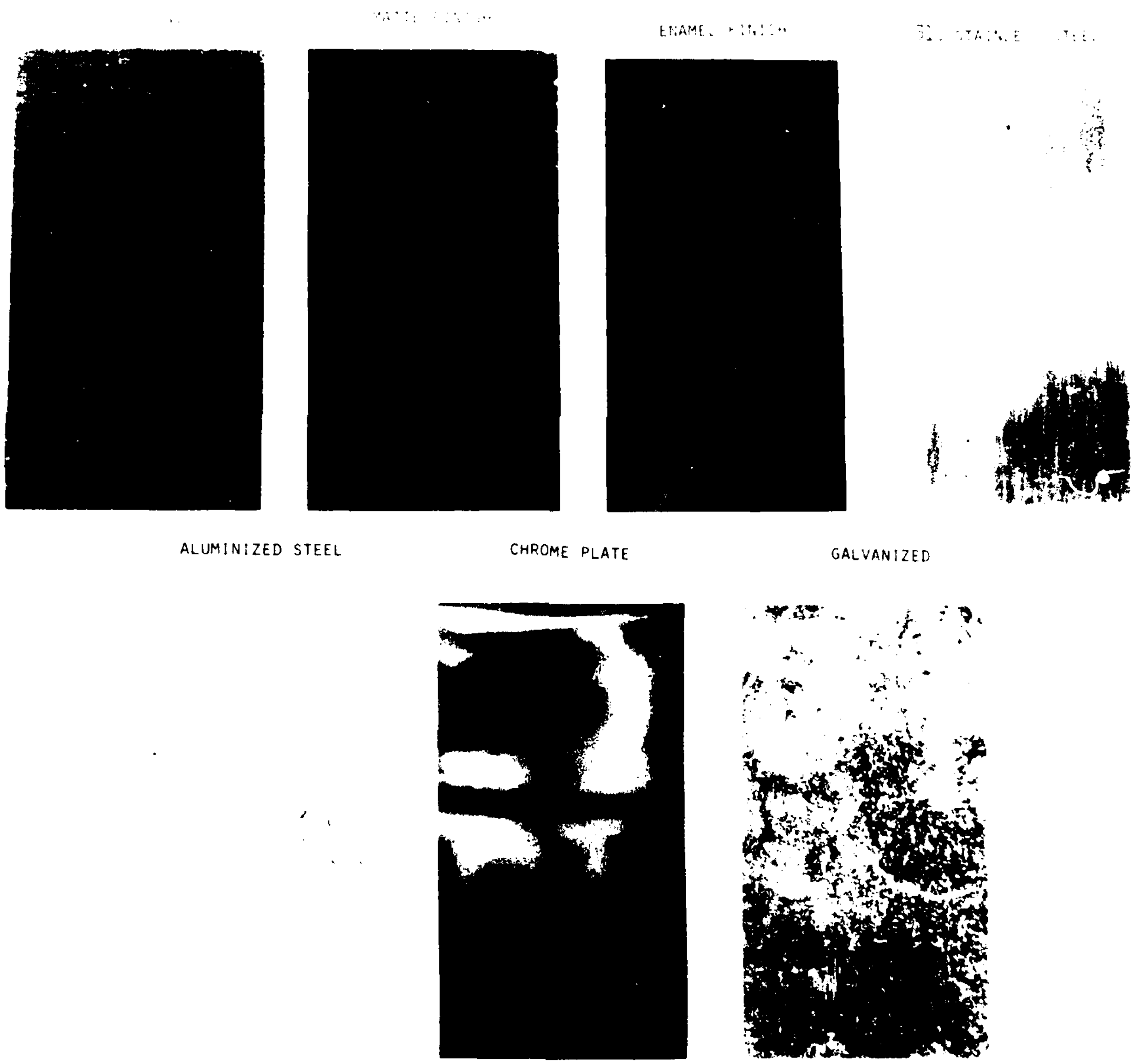


Figure 5. Humidity test specimens (after 14 days of testing).

oxide, basically Al_2O_3, appears dark in color due to the presence of a silicon addition (5%). However, these coatings remain protective since the brown iron oxide coloration, characteristic of steel substrate attack, is not visible. The remaining panels (enamel finish, chrome plate, and stainless steel) are identical in appearance to the specimens prior to test, indicating excellent corrosion resistance to the humidity environment.

The curves depicted in Figure 6 represent weight changes versus time of the systems studied (average of triplicate runs) exposed to 95% relative humidity at 120°F over a 45 day period. Again, as noted with 900°F thermal cyclic oxidation, initial weight decreases occur due to the presence of surface oil that had not been completely removed during specimen preparation. Under the given test conditions, a uniform moisture film was observed to condense on all test panels at sporadic times. The intermittent moisture condensation acted as a warm water rinse to further cleanse the surface of protective oils. The sharp initial weight decrease exhibited by the matte finish material can be explained with the aid of the scanning electron photomicrograph shown in Figure 7. The as-received finish is composed of flakes that produce a rough finish which is capable of retaining more oil than the smooth surface representing all other surface finishes investigated.

Aluminized and galvanized steels display the largest weight increases when compared to other material systems, as shown in Figure 6. Weight gains are attributed to ZnO_2 and Al_2O_3 formation as previously described. After ~20 hours of exposure, the aluminized steel weight gain is extremely small when compared to the galvanized system. The zinc in the galvanized coating affords substrate protection by behaving as a sacrificial anode and apparently is consumed at a greater rate than the aluminum which forms a protective oxide that protects unreacted aluminum to further enhance substrate protection. Therefore, the aluminized steel would be a better choice to extend stove pipe service for prolonged time periods where humid conditions contribute to deterioration.

The blue finish appears to be the most susceptible to corrosion attack in a high humidity environment, as shown in Figure 8. The approximately linear weight gain, shown in Figure 6, is indicative of the accelerated corrosion characteristic of the blue finish materials. When comparing Figures 8 and 5, a very small increase

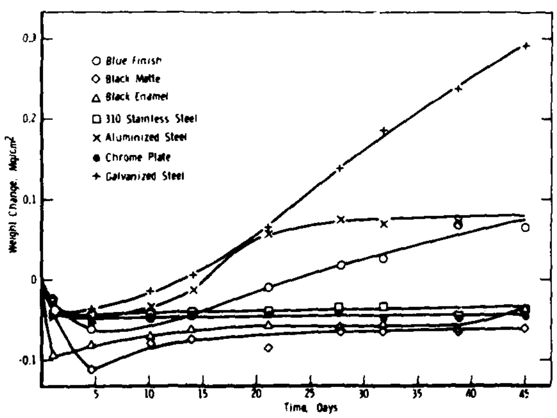


Figure 6. Weight change behavior of stove pipe candidate materials under humidity testing (95% R.H. at 120°F).

Figure 7. Matte finish (as received). Mag. 10X

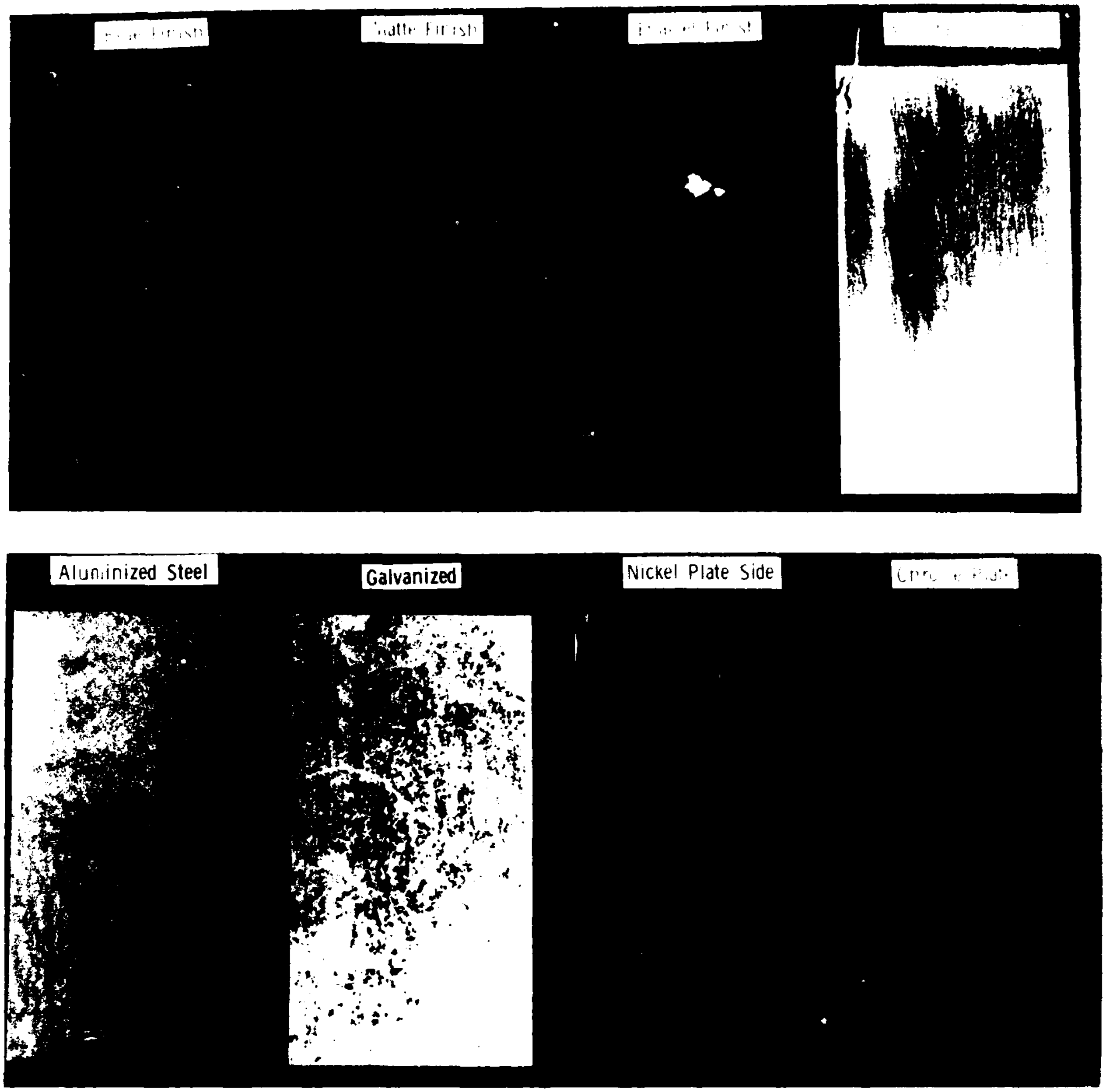


Figure 8. Humidity test specimens (after 45 days of testing).

in corrosion is observed on the matte finish when the exposure is increased from 14 to 45 days. This observation is confirmed by the very small weight gain shown over this time period in Figure 6. However, excellent protection is provided by the enamel paint finish until minute blisters form after 40 days and enlarge to the size displayed in Figure 8, representing 45 days of testing. Apparently, moisture becomes entrapped within blisters resulting in an enhanced substrate corrosion at local sites. Finally, 310 stainless steel and one sided chrome plate (reverse

side Ni plated) exhibit negligible weight changes with visible signs of corrosion occurring only at the nickel side of chromium plated mild steel, as shown in Figures 6 and 9 respectively. Corrosion on the Ni plate prevails as pits occurring throughout the porous finish that is characteristic of a thin electrolytic plate (0.02 mils) and along scratches. The combination of the thin Ni plate together with its low hardness, renders it susceptible to scratching and hence substrate exposure.

Weight gain changes and appearance of test panels exposed to humidity testing were found to be complementary criteria for evaluating corrosion resistance of the various material systems. Based on weight changes and visual appearance, it appears that the commercially available material systems investigated can be ranked in the following order of decreasing resistance to corrosion in humid environments: 310 stainless steel > chrome plate > aluminized coat > galvanized coat > black enamel paint > matte finish > blue finish.

Figure 9. Effect of humidity testing on nickel plate (45 days). Mag. 7.5X

Salt Spray

During salt spray testing, exposed edges of test panels were protected by coating the cut edges with wax. Thus, the development of a galvanic couple between edges and the adjacent plated or coated metal surfaces was prevented. Figure 10 depicts the effects of 5% salt spray testing (ASTM B117) on blued, matte, and enamel finishes after one day of test. Both bluing and matte surface treatments exhibit approximately equal amounts of gross corrosion, whereas corrosion is present to a lesser extent on the enamel panel. A network of cracks prevails throughout the enamel paint (note three large cracks on the panel lower portion) initiated by the hot salt spray. A hot water rinse revealed the mode of corrosion to be pitting. Exposure to hot water completely removed the enamel finish. However, an enamel panel, in the as-received condition, exposed to a hot water rinse remained intact on the mild steel substrate. Thus, the hot salts diffuse through the porous paint to degrade the paint/substrate bond.

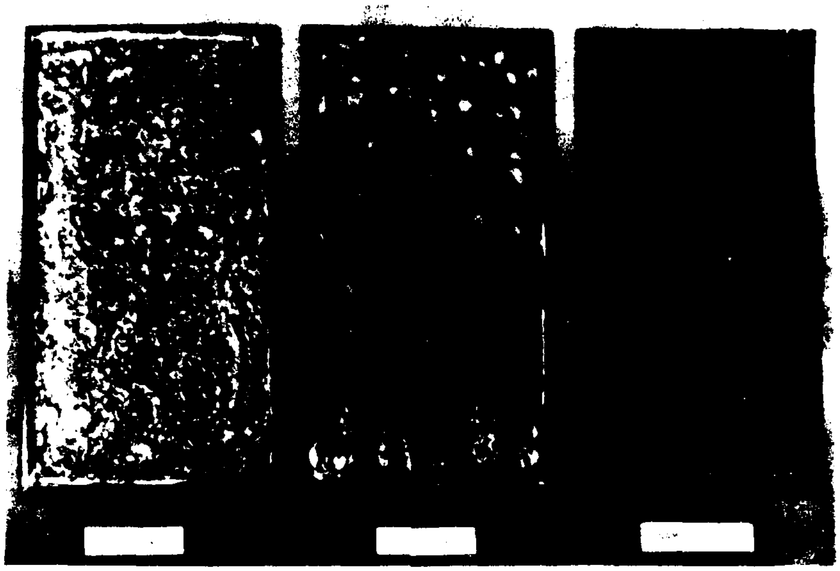
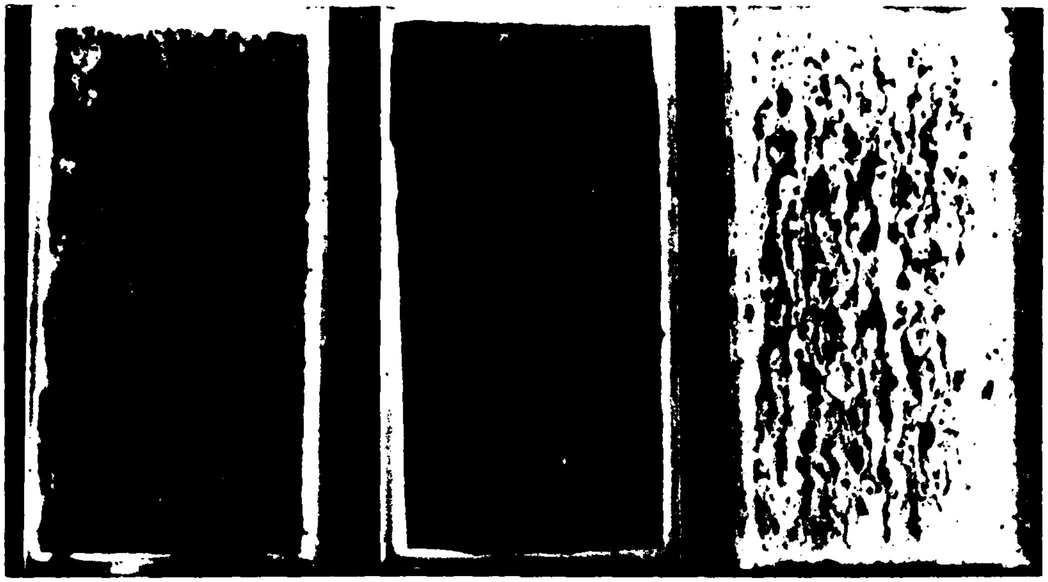


Figure 10. Salt spray test specimens after 24 hours.

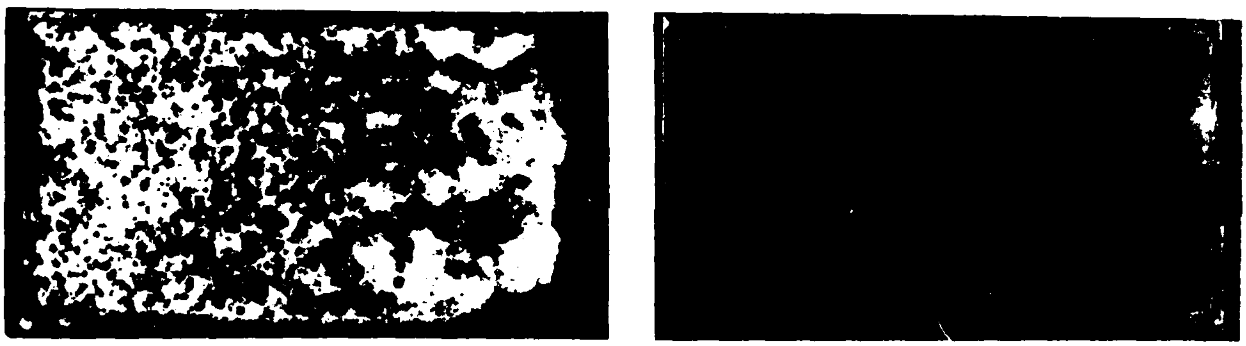
The remaining coated systems, including 310 stainless steel, exposed to 5% salt spray testing, are shown in Figure 11. The thin electrodeposited nickel with an inner flash copper plate becomes severely degraded after one day of exposure, resembling the behavior of the previously described oxide surface treatments. However, when overlayed with chromium, the protection afforded is extended to two days. Corrosion occurs as random pitting due to the porous nature of the thinly applied electrodeposited chromium. Mild steel protected with a galvanizing treatment corroded after three days of testing, at which time most of the sacrificial zinc had been converted to oxides. Corrosion of the aluminized coating occurred after 8 days indicating that the aluminized product is vastly superior to galvanized steel in a salt spray environment. Finally, 310 stainless steel afforded the best protection. Slight tarnishing was observed after 8 days of exposure to salt spray.

Current stove pipe costs for the material systems investigated are contained in Table 2. Commercially available blued, matte, enamel paint, chromized, and galvanized finished stove pipe prices are based on small quantity retail purchases. Since both aluminized steel and stainless steel stove pipes are not produced commercially, their listed prices are estimates obtained by adding to the cost of the sheet material an assumed cost for converting the sheet material to the stove pipe configuration (equal to the known cost for converting galvanized sheet to the stove pipe). Note that the cost of aluminized steel is fairly competitive with the galvanized steel and blue finish material.

Results based on the three types of corrosion tests performed, suggest that the aluminized, galvanized, and chromium plated mild steel, as well as bare 310 stainless steel, would be superior stove pipe material. A summary of ranking of materials based on performance in individual tests is shown in Table 3. Stove pipes fabricated from untreated stainless steel would be the best selection for maximum service life. However, an approximately tenfold increase in cost over the



Nickel Plate Side (1 Day) Chrome Plate (2 Days) Galvanized (3 Days)



Aluminized Steel (8 Days) 310 Stainless Steel (8 Days)

Figure 11. Specimens after 5% salt spray test.

presently used blued stove pipe renders this choice unattractive. Based on performance and cost, aluminized steel is the leading candidate material. A stove pipe fabricated from aluminized steel increases total unit cost by 78 cents and yet has the potential to extend service life substantially.

An additional factor that must be considered in selecting materials for military stove pipe use is the nonreflective requirement for the surface finish. Unfortunately, aluminized, galvanized, chromium plated, or stainless steels have highly reflective surfaces. Based on humidity test results, aluminized mild steel exposed to controlled temperature and humidity conditions will impart a dull dark finish to the surface, possibly acceptable for military applications. Heat treating at 900°F in an oxidizing atmosphere has shown that both galvanized and stainless steels acquire a dull, dark coloration. Likewise, the nickel plated material, which is the other side of the chromium plated material, became dull black in color when exposed to an air environment at 900°F for a short time. Although salt spray

Table 2. STOVE PIPE COSTS (6" O.D. by 2' LONG)

Mild Steel Finish	Cost (Dollars)
Bluing	2.32
Galvanized	2.57
*Aluminized	3.10
Matte	3.57
Chromized	6.16
Enamel Paint	7.00
Type 310 Stainless Steel*	25.00

Estimated*

Table 3. MATERIAL RANKING ACCORDING TO SPECIFIC TEST RESULTS

Cyclic Oxidation	Humidity	Salt Spray
310 S.S.	310 S.S.	310 S.S.
Aluminized	Chrome Plate	Aluminized
Galvanized	Aluminized	Galvanized
Enamel Paint	Galvanized	Chrome Plate
Chrome Plate	Enamel Paint	Enamel Paint
Blue Oxide	Matte Oxide	Matte Oxide
Matte Oxide	Blue Oxide	Blue Oxide

testing showed gross degradation of the substrate steel protected with a thin nickel finish after one day, failure was attributed to the porosity inherent in thin electrodeposited nickel films rather than the nickel itself. Therefore, nickel electroplated to a suitable thickness, could be heat treated to acquire an acceptable appearance and extend stove pipe service at moderate costs.

CONCLUSIONS

Results of laboratory tests including (1) cyclic oxidation between 900°F and RT, (b) 95% relative humidity at 120°F, and (c) 5% salt spray indicate that stove pipes fabricated from aluminized, galvanized, or chromium plated mild steel as well as type 310 stainless steel have the potential to extend service life significantly; whereas, only small gain, if any, can be achieved with a matte oxide or enamel paint finish when compared to currently employed blued steel. Unfortunately, in their fabricated condition, the more promising materials possess a metallic luster finish which is not compatible with the nonreflective surface finish required for military use. However, the necessary nonreflective surface can be imparted to 310 stainless and galvanized steel by a 900°F heat treatment in an oxidizing atmosphere. Also, the nickel side of chromium plated steel responds favorably to this heat treatment and if electroplated to a sufficient thickness would, in itself, be a viable material for extending stove pipe service.

The 310 stainless steel was shown to be the most corrosion resistant material under the test conditions employed, but its cost is prohibitive, an approximate tenfold increase compared to the presently utilized blue finished steel. Aluminized mild steel was found to be the most cost effective, based on overall corrosion resistance and cost per fabricated unit, a 78 cent increase when compared to a blue finish stove pipe.

RECOMMENDATIONS

To confirm laboratory results, we recommend that stove pipes fabricated from the more corrosion resistant materials (type 310 stainless steel, galvanized, aluminized, chromium plated, and nickel plated mild steel) be treated to acquire a nonreflective finish and then installed in a separate U.S. Army tent heater or stove and field tested under controlled conditions. Chromium plated and nickel plated coatings should have thicknesses comparable to commercially available aluminized and galvanized coatings in order to obtain a reliable assessment of all materials. Effects on coating thicknesses should be evaluated. Baseline data would be established by controlled field testing of blue finish stove pipes under similar conditions.

In addition, specific heat treatments must be established for the aforementioned materials or preferably the most cost effective material to convert the characteristic metallic luster to a nonreflective surface finish as required by the U.S. Army.

Finally, a cost comparison study based on the specific stove pipe sizes and quantities required for Army usage should be made.

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Joseph J. Falco and Milton Levy

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